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FLY ASH/CEMENT PACKING FOR LINGAN MINE: FINAL APPRAISAL AND TRIAL PROPOSAL

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FLY ASH/CEMENT PACKING FOR LINGAN MINE: FINAL APPRAISAL AND TRIAL PROPOSAL

by

P. Cain*, A. Harvey** and T.R.C. Aston*

ABSTRACT

Recent research in Nova Scotia has highlighted fly ash/cement mixtures as a possible alternative to imported pump packing materials. This report presents a final appraisal of fly ash/cement mixtures as a packing material for use at Lingan Mine and presents details of a proposed underground trial of the selected packing system.

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UTILISATION D'UN MÉLANGE DE CENDRES VOLANTES ET DE CIMENT POUR LE REMBLAYAGE À LA HOUILLÈRE LINGAN ; DERNIÈRES ÉVALUATION ET PROPOSITION D'ESSAIS

par

P. Cain*, A. Harvey** et T.R.C. Aston*

RÉSUMÉ

Les derniers travaux de recherche sur le remblayage réalisés en Nouvelle-Écosse ont souligné que les mélanges de cendres volantes et de ciment pourraient remplacer les matériaux de remblayage par pompage importés. Le présent rapport présente une dernière évaluation de l'emploi des mélanges de cendres volantes et de ciment comme matériaux de remblayage à la houillère Lingan. Il donne en outre les détails d'une proposition visant à utiliser ce système de remblayage dans le cadre d'essais souterrains.

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INTRODUCTION

Monolithic pumped packing was introduced at Lingan Mine, Nova Scotia in March 1985 to reduce air leakage across the longwall waste in the 9 East district. Underground investigations by the Cape Breton Coal Research Laboratory (CBCRL) revealed a marked improvement in ventilation efficiency with no loss of strata control in the gateroads (1). Subsequently, monolithic pumped packing has been used in the 10E district and will also be installed in the 11E district, due to start operations in September 1987.

The pumped packing system currently used is the Astrapack system. The pack material is supplied by Pozzament Ltd. from its works in the U.K. It is a conventional low solids, two grout system that provides effective early support and a good ventilation seal. However, this system suffers from two major disadvantages; the high cost of the imported materials and wastage associated with handling the material in bags (losses of up to 20% are standard). For these reasons, considerable efforts have been made to evaluate alternative packing systems, particularly those using inexpensive, locally available materials.

Recent research in Nova Scotia has concentrated on the development of a packing system using fly ash and ordinary portland cement (OPC). Both materials are conveniently and inexpensively available, and lend themselves very well to mechanised packing methods. Their use in gateroad packing was pioneered in the U.K. at Parsonage Colliery in Lancashire in a packing system known as Flashpack where it has proved very successful.

The apparent success of Flashpack at Parsonage Colliery prompted the Cape Breton Development Corporation (CBDC) to arrange for two engineers to visit the U.K. to assess the applicability of the Flashpack system to operations at Lingan Mine. The CBDC delegation was accompanied by representatives from CBCRL and L.E. Shaw Ltd. The favourable impression obtained by the visit (2) prompted further investigations into fly ash/cement packing by CBDC, CBCRL and L.E. Shaw Ltd.

This report briefly reviews the Parsonage Flashpack system and describes recent research in Nova Scotia into the application of fly ash/cement packing systems before outlining requirements for a successful packing system at Lingan Mine. This is followed by a proposal including surface and underground trials and details of associated costs and benefits.

FLY ASH/CEMENT PACKING AT PARSONAGE COLLIERY

The original design work on fly ash/cement mixes for use in mine packs was done by the British Coal Technical Services Headquarters in Great Britain. A prototype system was installed at Parsonage Colliery, near Manchester, England, where it has been successful in preventing spontaneous combustion and controlling gateroad deformation.

The Parsonage system involves the mixing of two grouts: a fly ash/accelerator/water mixture and a cement/water mixture. The fly ash grout also contains a small amount of bentonite to maintain a suspension. The two grouts are pumped to the packhole separately where they meet at a mixing nozzle from which they are sprayed onto the pack under construction. The chemistry of the mix results in an immediate gelling of the mixture, allowing a high density, quick setting pack to be placed quite rapidly (up to 22 m^3/hr) without the use of special shuttering or packing bags. A more detailed account of the Parsonage Colliery Flashpack system is given in Appendix A (3).

RECENT RESEARCH IN NOVA SCOTIA

Prompted by the favourable impression of fly ash/cement packing at Parsonage Colliery, CBDC, CBCRL and L.E. Shaw Ltd. undertook further research into two main aspects: optimum mix designs for Nova Scotian raw materials and mechanised handling systems for materials delivery.

MIX DESIGN

The mix design research was conducted by W.S. Langley and Associates Ltd. of Halifax, N.S. under subcontract from L.E. Shaw Ltd. on a Department of Supply and Services Canada contract entitled "Development of Engineering Data on Nova Scotia Fly Ash" (4). Laboratory design work was followed by two surface trials of the packing system using the mix designs thus developed.

LABORATORY DESIGN WORK

Laboratory design work was undertaken to determine optimum mix proportions for fly ash and cement powders available in Nova Scotia.

In order to test a range of mix ratios, two basic slurries were produced and mixed in different quantities. The basic slurry constituents and the sources of the raw materials are given below:

FLY ASH SLURRY

Component	Quantity (kg/m^3)	Source
Fly Ash	1436	Lingan Power Station
Al_2SO_4 or Fe_2SO_4	107	Local Chemical Supplier
Bentonite	14	Western Canada
Water	362	

CEMENT SLURRY

Component	Quantity (kg/m^3)	Source
Portland Cement Type 10	1326	Brookfield Works
Water	578	

These two slurries were combined at various ratios to provide the following mixes:

Fly Ash Slurry:Cement Slurry Ratio	Mix Quantities (kg/m^3)				
	Fly Ash	Fe/Al_2SO_4	Bentonite	OPC	Water
1:1	718	53.5	7.2	663	470
2:1	962	72	9.6	438	433
3:1	1077	80.3	10.8	332	416
4:1	1148	85.6	11.5	265	405
5:1	1196	89.2	12.0	221	398
6:1	1230	91.7	12.3	190	393

Specimens of the mixes were cast in cube moulds (100 mm x 100 mm x 100 mm) and tested at 24 hours, 7 days and 28 days intervals after casting. The instantaneous gelling properties of the mixtures brought about by the flocculant effect of Fe_2SO_4 or Al_2SO_4 made casting the moulds difficult, and low strengths obtained at ages less than 24 hours affect this.

Both Al_2SO_4 and Fe_2SO_4 additives were tested, with Al_2SO_4 proving to provide higher strengths. The results of the tests are shown in Figures 1 and 2.

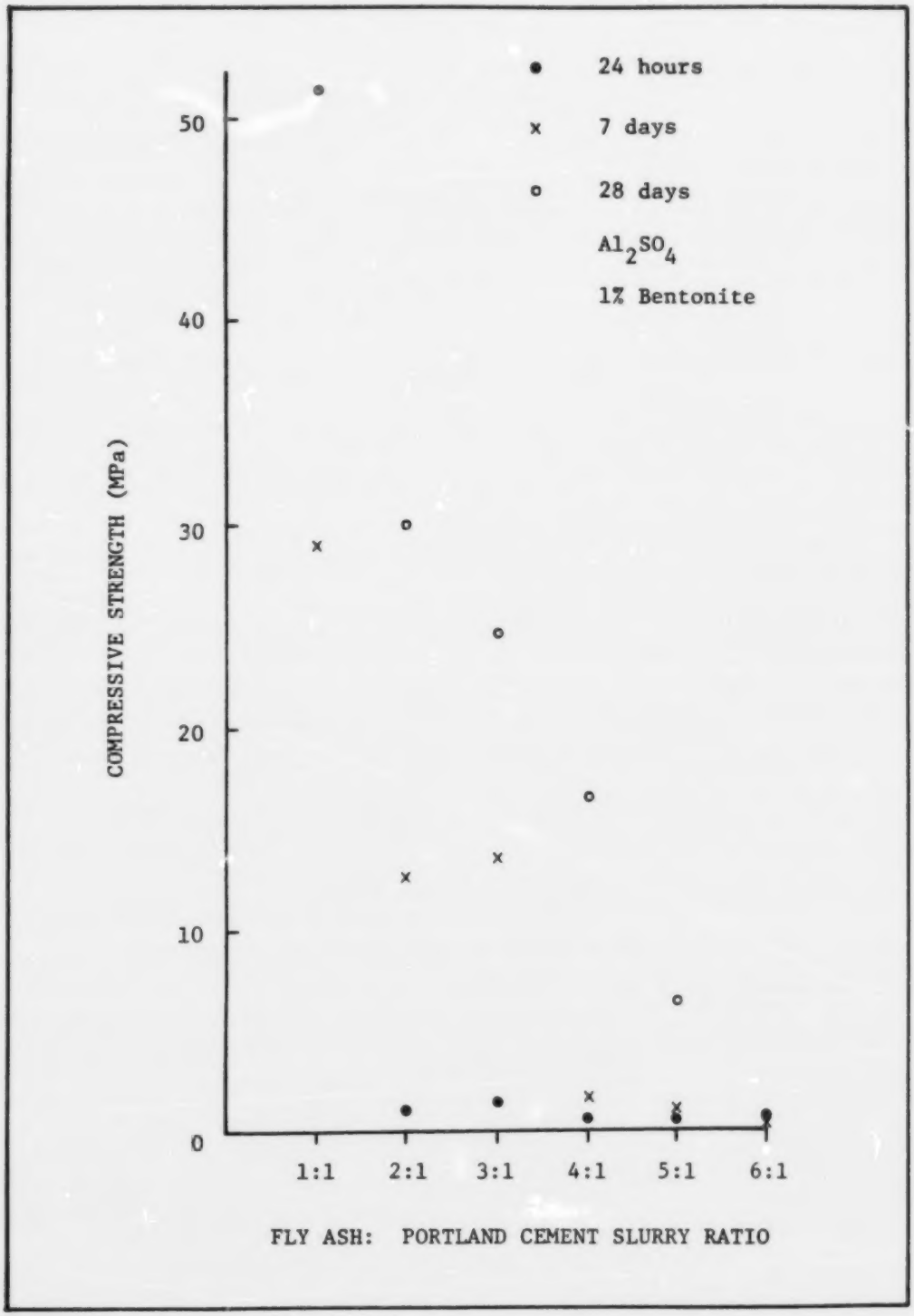


Figure 1 - Compressive strength versus fly ash content - Al_2SO_4

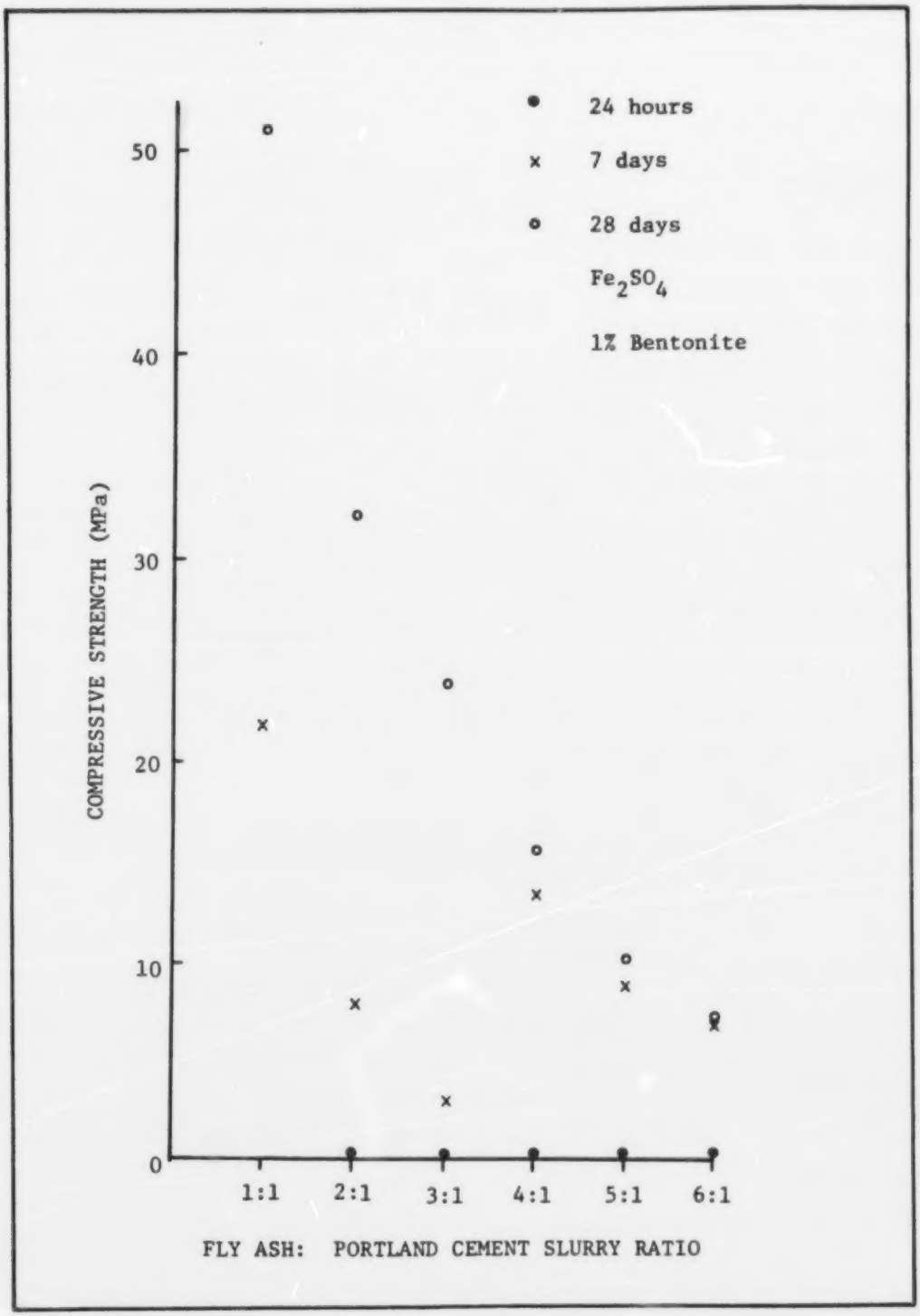


Figure 2 - Compressive strength versus fly ash content - Fe_2SO_4

FIELD TRIALS

Two field trials of fly ash packing have been carried out. The first at Lingan Mine was not entirely successful because the equipment used did not allow accurate control of mix proportions. The second trial at the Nova Scotia Sand and Gravel works at Shubenacadie, N.S. was more successful (see Appendix B for trial schedule).

LINGAN COLLIERY TRIALS

Flashpack field trials were conducted at the Cape Breton Development Corporation's Lingan Mine site on August 21 and 22, 1986. The trial mine packs, constructed above ground, were based on the research data gathered in Task 5 of Supply and Services Canada Contract No. 14SQ.23440-4-9303 (4). The purpose of the field trials were to determine the relationship between laboratory and field data on mixes and to assess the viability of further research and development of mine packs utilizing local material.

The fly ash slurry (fly ash + ferrous sulphate or aluminum sulphate + bentonite + water) was proportioned and mixed in two upright cylindrical mixers and pumped by a Moyno pump. The Portland cement/water slurry was mixed and pumped by a Moyno grout pump. The slurries pumped independently converged at a nozzle.

The composition of the two slurries were:

SLURRY 1	
Fly Ash	1436 kg/m^3
Al_2SO_4 or Fe_2SO_4	107 kg/m^3
Bentonite	14 kg/m^3
Water	362 kg/m^3
SLURRY 2	
Portland Cement Type 10	1326 kg/m^3
Water	578 kg/m^3

Laboratory test results indicated that a mixture composition of 4 parts of Slurry 1 to 1 part of Slurry 2 (by volume) should approximate the mine work requirements for strength.

The following mix proportions were attempted in the field:

Mix No.	Mix Ratio Slurry 1:Slurry 2	Al_2SO_4	Fe_2SO_4
1	5:1	Full Dose	—
2	5:1	—	Full Dose
3	5:1 (Repeat)	—	Full Dose
4	5:1	½ Dose	—
5	6:1	Full Dose	—
6	6:1	—	Full Dose
7	3:1	Full Dose	—
8	6:1	Full Dose	—
9	4:1	Full Dose	—

The trial mixes as outlined above were not completely successful. The mixes did indicate, however, that the aluminum sulphate (Al_2SO_4) performed superior in quick gelling compared to the ferrous sulphate (Fe_2SO_4).

The mixes were unsuccessful because of a number of factors, including:

1) The solid materials were batched by bag or part bags estimated. Water was measured by a volumetric measurement of the mixer drum on the fly ash mixer and metered on the Moyno grout pump.
2) The cement was added through the cement hopper in predetermined amounts. The cement feed to the auger was adjusted by opening or closing the gate as required. It was determined toward the end of the testing that the gate adjustment was not an effective way of controlling cement flow. In the final analysis, the cement slurry equipment was effective for one rate of flow only.
3) The Moyno pump required a flow of water to keep the pump cool and lubricated when not in use for pumping slurry. This caused some mixing of grout and water, and the exact time of transition from water to slurry was indeterminable.
4) The fly ash slurry flow could only be calibrated when the cement slurry was not flowing in the line. The interference of the two

slurries in the nozzle would undoubtedly affect the flow in the individual lines.

5) The time at which the two slurries entered the nozzle could not be determined. Thus, the opportunity existed for only the fly ash slurry to be placed in the test section first and cause poor gelling characteristics.

Due to the above factors, of which No. 2 is considered the most significant, compressive strength testing of the hardened packs were discontinued after 24 hours.

The testing, even with significant shortcomings, indicates a strong potential for success with the slurries accurately proportioned. Therefore, it was recommended that the testing be repeated with modifications to the equipment.

SHUBENACADIE TRIALS

Following the Lingan trials, more accurately metered pumps were assembled at the Nova Scotia Sand and Gravel Quarry in Shubenacadie, N.S. Fly ash and cement slurries were mixed as before, except that aluminum sulphate was the only accelerator tested. The mixed slurries were stored in drums prior to pumping via positive Bean Royal pumps. The rotation speed of the pumps could be controlled independently to provide a given flow, and subsequently interlocked to maintain a given ratio regardless of any variation in hydraulic flow from the hydraulic pump.

The pumps delivered the slurries along separate grout lines to a nozzle with a spiral built inside to provide sufficient turbulence to mix the two grouts prior to discharge. (The equipment used for the field trials is shown in photographs 1 to 5.)

PROCEDURE

Three trials were conducted in the field and denoted as the relative proportions by volume of fly ash and aluminum sulphate slurry to a

Portland cement slurry. The three trials were 2:1, 3:1 and 6:1. The proportions were as follows:

		2:1	3:1	6:1
Portland Cement Type 10	(kg/m^3)	442	332	189
Fly Ash	(kg/m^3)	957	1077	1230
Aluminum Sulphate	(kg/m^3)	71	78	92
Water	(L/m^3)	464	437	405

The above three trials of 2:1, 3:1 and 6:1 are shown in photographs 6, 7 and 8 respectively.

TESTING

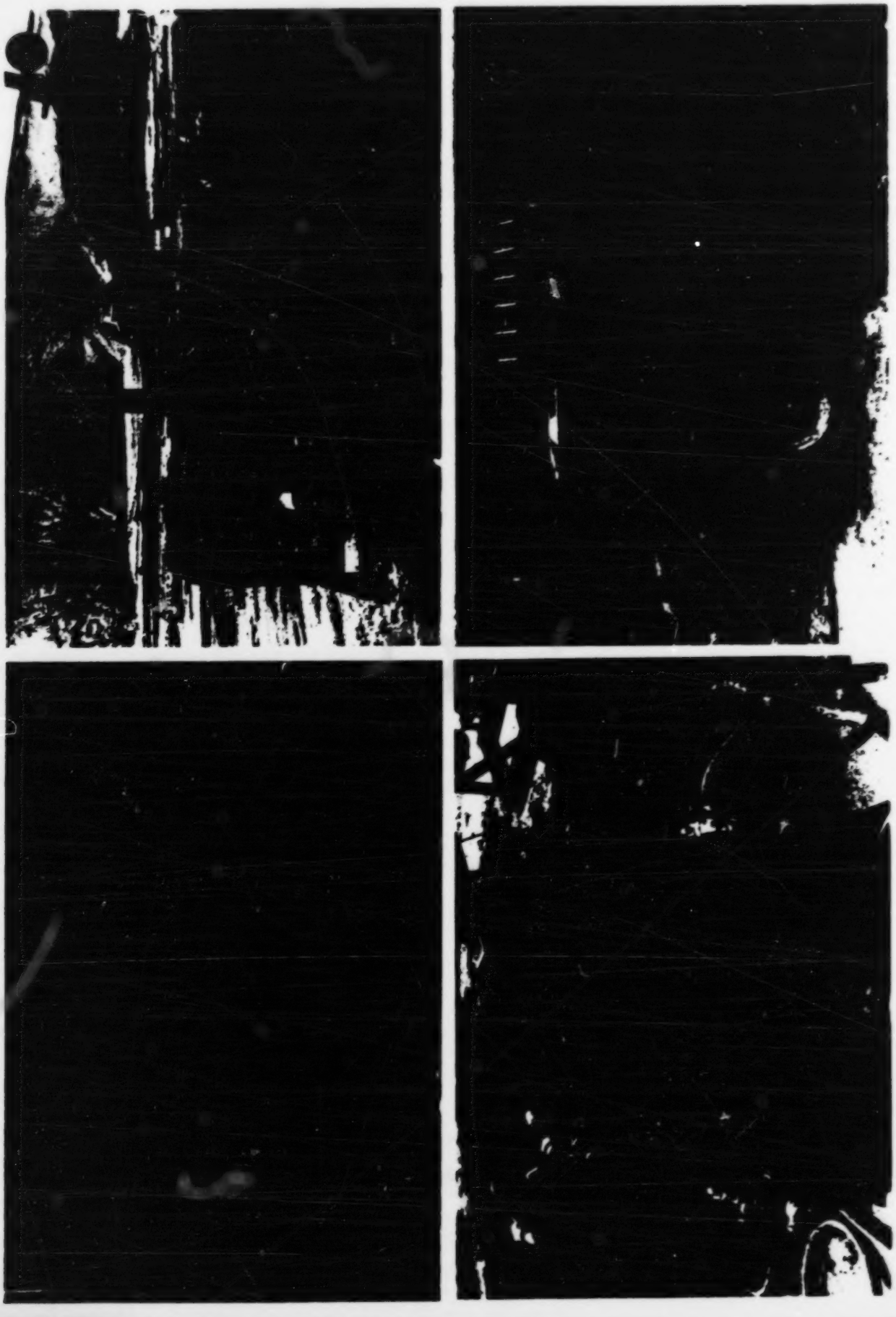
One hundred (100) mm cube molds were attached to the interior of each compartment and 'shot' full of the grout during the trials. The following test results were obtained on the cubes:

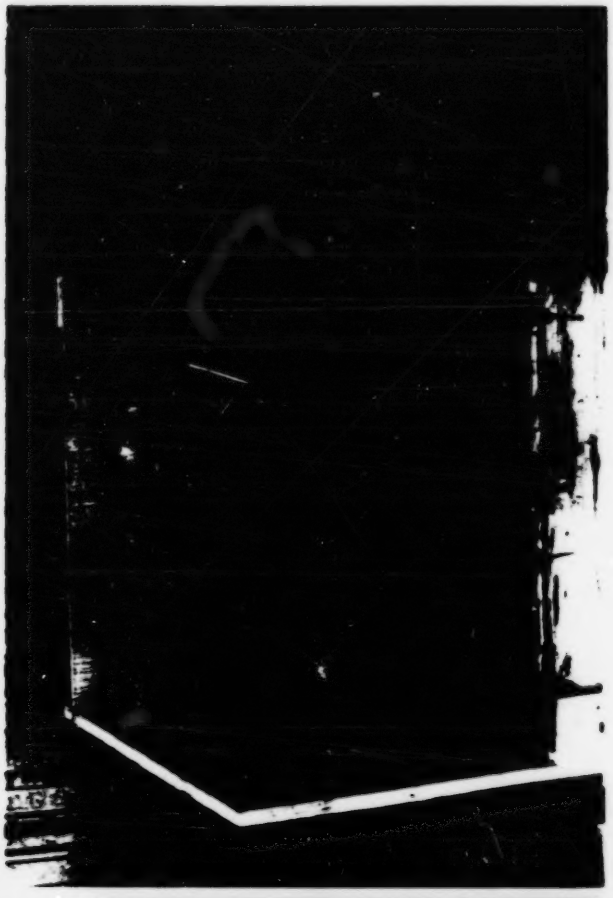
Age at Test	Compressive Strength MPa		
	2:1	3:1	6:1
3 hours	-	0.32	-
5½ hours	0.39	-	-
7 days	5.8	1.3	0.7
28 days	12.6	8.3	1.3

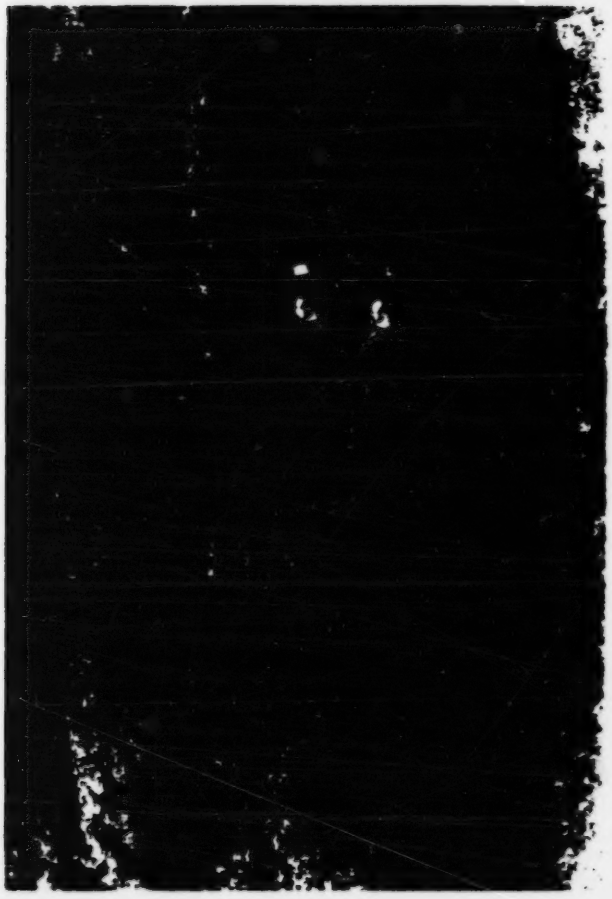
In addition to the cubes, cores were taken from the completed field specimens and compressive strengths determined at various ages.

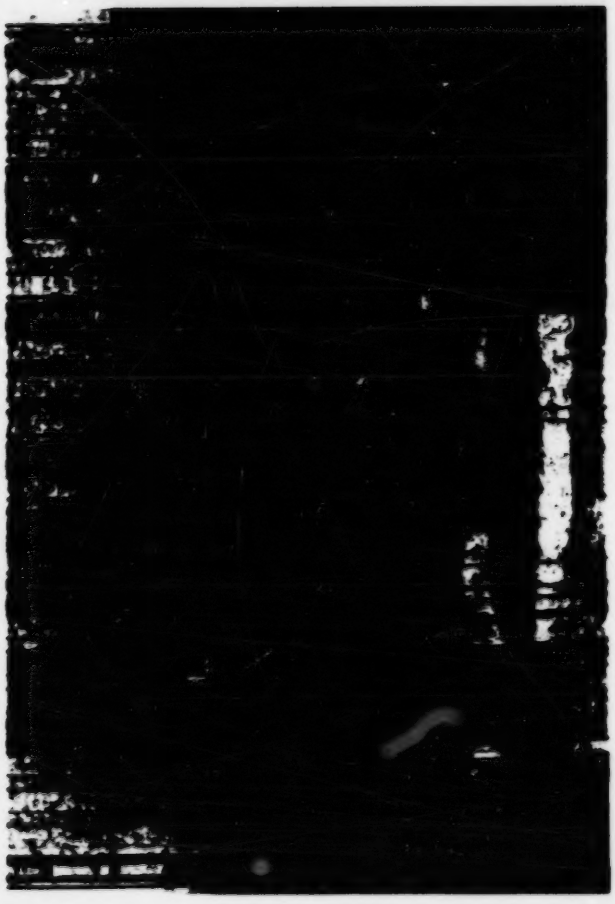
The following test results were determined on 95 mm diameter cores (appropriately corrected for length).

Age at Test	Compressive Strength MPa		
	2:1	3:1	6:1
7 days	1.3, 1.7	1.0, 1.1	0.7
11 days	1.9	-	-
15 days	-	2.4	-
28 days	2.6	-	-
40 days	2.3	-	-









The cores from the test specimens tested substantially lower than the cube specimens cast integrally with the field specimens.

Examination of the cores extracted from the specimens exhibited several major flaws which affect the compressive strength, namely:

1) A random layering or lamination effect with virtually no bond between laminates.
2) Non-homogeneous mixing of the two slurries.

ANALYSIS OF DATA

The equipment utilized for the field trials maintained accurate proportions of the two grout systems. A volumetric check was made on the proportions during pumping and found to be satisfactory. The grouts were pre-mixed and proportioned by weight.

The volumetric capacity of the Bean Royal pumps was relatively low for the size of the discharge lines and nozzle; thus, there was a tendency for non-uniform mixing through the nozzle. The small volume of grout ejected from the nozzle allowed for a layering affect in the bins and due to the quick gelling of the material, a structural bond was not established between layers.

The cubes which were cast integrally with the pack showed no signs of layering, voids or segregation, and provided compressive strength in the desireable range at 7 and 28 days. The early strength is somewhat low and may be characteristic of the cementitious system. The unit water content could be reduced considerably maintaining a pumpable mix. A reduced unit water content will increase the compressive strength at all ages.

It is recommended that any equipment assembled for the placement of in situ mine packs have all components sized compatibly to ensure complete and homogeneous mixing of all materials. The nozzle size and configuration is extremely important and one similar to that used at Parsonage Colliery would be satisfactory.

SYSTEM REQUIREMENTS

The requirements of a successful fly ash/cement packing system can be summarised as follows:

- raw material costs must be economic,
- raw materials should present no health hazard,
- raw materials transport should be efficient,
- pack construction must be manpower efficient and not delay face advance, and
- pack properties must be adequate to provide strata control and ventilation seating.

COSTS

Preliminary cost analyses have been undertaken at CBCRL. The main materials, equipment and costs are given later and detailed in Appendix C. Raw material costs for fly ash/cement packing are substantially less than those for the current method.

HEALTH AND SAFETY

The effect of the packing materials on health and safety in the mine is of prime importance. The beneficial effects of early support at the face end on strata control safety and of ventilation sealing on improved airflows (and hence lower methane and dust concentrations) associated with monolithic packing in the Sydney Coalfield are well documented (1) and follow patterns observed in many other locations.

The properties of the raw materials used in fly ash/cement packing and their effects on workers exposed to them are summarised in Appendix D. Provided that reasonable standards of work practise are adopted, there is no evidence to suggest any health hazard to the mine work force.

MATERIALS TRANSPORT

Current pack materials transport methods are expensive and inefficient; wood blocks are man-handled several times prior to use and transportation of dry powders in bags leads to expensive losses. Although

material transport methods at Lingan Mine are under review, several alternatives are available for transportation of Flashpack constituents:

1) long-distance pumping (in slurries),
2) pneumatic handling,
3) bulk material cars or
4) a combination of 2 and 3 of the above.

Neither long-distance pumping nor pneumatic handling have been considered in any great detail. Long-distance pumping would require very long pipe ranges. The high pressures required to deliver the slurry, the risk of blockages and the possibility of excessive wear due to the abrasive nature of the fly ash mitigated against this method. Pneumatic handling was ruled out because the long distances involved would require the installation of two complete, technically complex systems, the cost of which could not be justified in view of the small quantities of materials involved.

The use of bulk material cars to transport a fly ash/cement blend from the surface to a gateroad bunker was selected as the most appropriate transportation method. Two surface silos for fly ash and cement would fill the bulk cars with a blended fly ash/cement powder through a mixer. The bulk material cars would feed a dry bunker in the district tailgate, where the mixer and pump would also be stationed. The tailgate location of the bunker/mixer/pump station would require lines to be maintained along the faceline and permission for electric motors in the return, but it would considerably reduce congestion in the maingate face end. At a later date, tailgate packing could be implemented very easily. The other component of the packing system, the aluminum sulphate accelerator, will be delivered in bulk liquid form to the pithead. Tank wagons will be used to transfer the accelerator to the tailgate packing station, where it will be stored prior to use.

A combination method of delivery is also possible, comprising bulk fly ash and accelerator delivery from a surface silo to an outbye pumping station, and delivery of bagged cement to an inbye pumping station. This would require two pumping stations, more manpower and excellent communication between the two pump sites, but one less surface silo. This method has been discounted here.

PACK CONSTRUCTION

Fly ash/cement packing offers major advantages in pack construction. Packing rates of up to 22 m^3/hr can be achieved. No shuttering is required and the necessity of handling one-hundred thirty 15 cm x 15 cm x 1.5 m hardwood pieces several times before finally using them in the pack is removed.

If face end manpower can be rationalised, only two men are required for pack construction; one man at the pumps and one at the nozzle.

PACK PROPERTIES

The major requirements of a pack are that it provides a good ventilation seal and adequate support to maintain the roadway.

Experience at Parsonage Colliery has shown that fly ash/cement packs, when placed to the roof of the seam, can reduce air leakage across the gob and prevent spontaneous combustion. A similarly effective ventilation seal is achievable at Lingan Mine if a properly supervised standard of pack placement is maintained.

The support properties and dimensioning of the production pack will be determined to some extent during underground trials. Laboratory and surface mix trials have indicated that the fly ash/cement mixtures available in the coalfield can provide the required support, and meet the British Coal requirements for rapidly setting pack materials. As a guide, the following rate of strength development can be used:

2 hours	0.4 MPa (58 psi)
12 hours	2.4 MPa (348 psi)
7 days	5.2 MPa (754 psi)
14 days	6.7 Mpa (971 psi)
28 days	8-11 Mpa (1160-1595 psi)

TRIAL PROPOSAL

In the authors' opinion, the above demonstrates that Flashpack could provide an economic alternative to current monolithic packing methods.

The following trial proposal is based on surface and underground testing to be followed if successful by full underground implementation.

SURFACE TRIAL

The surface trial at Lingan Mine would use the same principles of mixing outlined above and would determine the effectiveness of preblended fly ash/cement powders and the characteristics of the final pack. Most of the necessary equipment is now available at the mine, with the exception of a colloidal mixer. The equipment requirement is as follows:

- two power packs
- two pumps
- mixing tanks

One power pack/pump will be used for the aluminum sulphate, the other power pack/pump and mixing tank will be used for the fly ash/cement blend. Batch mixing tanks are available at Lingan Mine, but experience has shown that colloidal mixes give better results and one should be obtained for the trial, either rented or from within the Corporation.

Raw materials for the trial will be supplied as follows:

- fly ash/cement - preblended by L.E. Shaw Ltd. in ratios of 3:1, 4:1 and 5:1 delivered in 25 kg bags palleted.
- aluminum sulphate - as a solution in drums from General Chemicals Ltd., Moncton.

Packs up to 2 m^3 should be poured to determine:

- full size pack strengths
- choice of nozzle type
- strength of pack mixes

UNDERGROUND TRIALS

On the successful completion of the surface trials, an underground trial should be initiated. It could be implemented on any longwall, but the assumption made here is that an east side wall will be selected. Using the

transportation system outlined previously, the initial phase of the trial would replace only the present Astrapack with Flashpack over a distance of 150 m (500 ft). Training and supervision of packers in this phase is of the utmost importance as is monitoring of pack and gateroad performance. Another important feature is the provision of a dedicated communication system between the pumps and the packhole, especially if the bunkers/mixing station are to be carried in the tailgate.

After the initial 150 m trial, full backfilling should be implemented and monitored for a further 150 m (500 ft) (Figure 3).

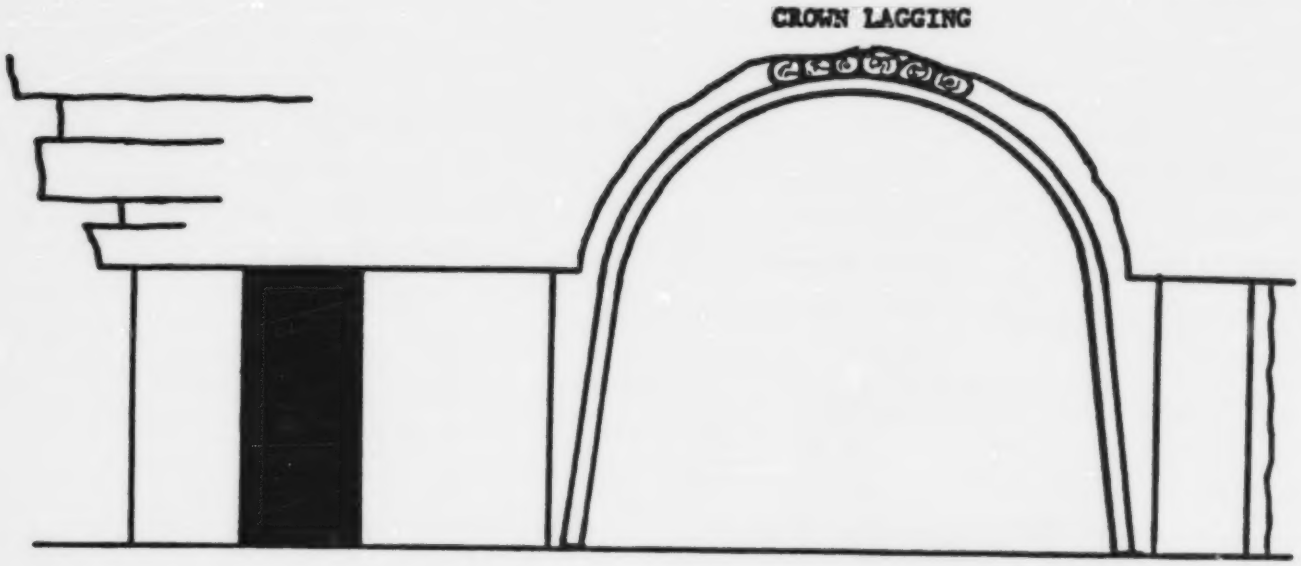
Very little packhole preparation will be required because of the flash setting of the pack. During the full backfilling trial, full shuttering of the arch with corrugated sheets will be required.

Details of the equipment required for the underground trial are given in Appendix C. Surface silos will be required and also a blender for the fly ash and cement. These can be purchased outright, but L.E. Shaw Ltd. are also prepared to lease the equipment and charge a higher cost for the fly ash.

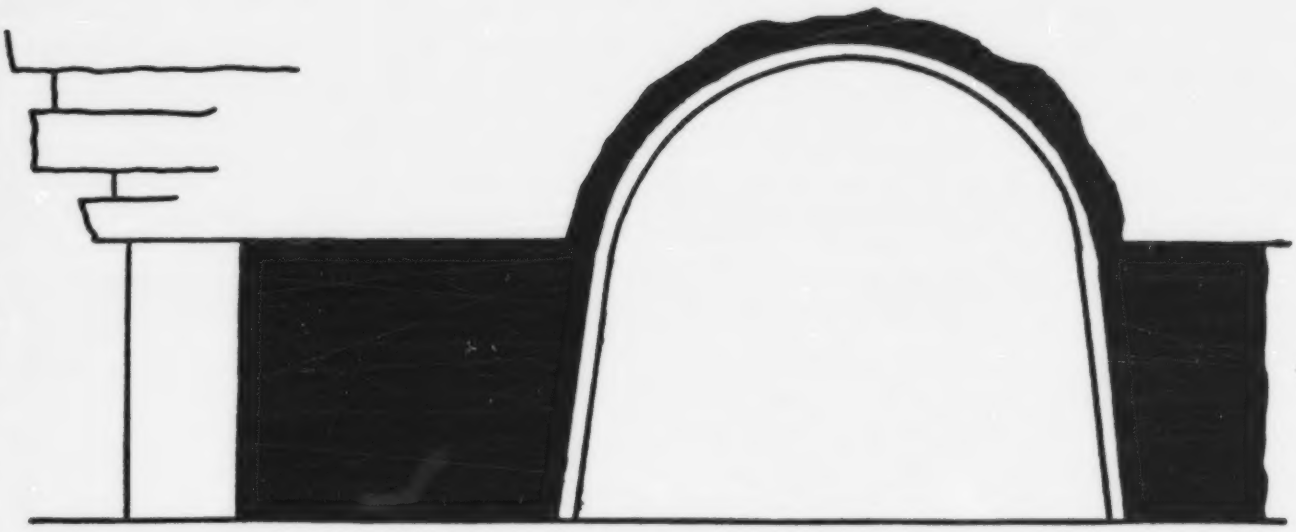
Bulk handling cars required for transportation of the fly ash/cement blend from the surface to the gateroad bunker are available from Colcrete Ltd. with a capacity of 4.5 tonnes. The fly ash/cement blend required for each metre of advance is 3.80 tonnes (1.16 tonnes/ft) for simple Astrapack replacement and 10.57 tonnes (3.22 tonnes/ft) for full backfilling. An 18 tonne gateroad bunker will allow continuous packing increments of 4.7 m (15.5 ft) for Astrapack replacement and 1.5 m (5 ft) for full backfilling. Four bulk handling cars will be required to refill the bunker. Assuming 4 cars full in the gateroad, 4 being filled, 4 in transit and 2 spares; 18 cars are required. The largest manufactured bunker quoted for the trial was 6 tonnes, but a larger one can be built or bought elsewhere or the 6 tonne bunker can be refilled during the packing process.

The aluminum sulphate will be handled in 750 L tank wagons. The liquid contains 48.8% by weight of aluminum sulphate and has a density of 1.31 kg/L. For an aluminum sulphate requirement of 86 kg/m^3 of pack, 135 L will be required per m^3 or 375 L/m (114 L/ft) for replacement and 1006 L/m (306 L/ft) for full backfilling.

Equipment and equipment costs are detailed in Appendix C.



STAGE 1 - ASTRAPACK REPLACEMENT



STAGE 2 - FULL BACKFILLING

Figure 3 - Proposed fly ash trial stages

COSTS

A full cost estimate is given in Appendix C and summarised below in Table 1. Capital equipment costs make up a much higher proportion of the total costs for Flashpack than they do for Astrapack, but the material costs are substantially less. Equipment has been assumed to have no value at the end of its estimated life. If proper maintenance is followed, these costs could be reduced considerably. Total cost for full backfilling is $7.60 higher than the current packing method. However, the reduction in wood transportation and handling costs and improvements in gateroad conditions would help to offset this.

Table 1 - Summary of costs

	Costs per metre ($)		
	Current Method	Astrapack Replacement	Total Backfilling
Pump Pack	481.29	220.00	611.73
High side chock	169.34	169.34	-
Low side chock	56.29	56.29	-
Equipment	22.11	135.83	135.83
Total cost/m	729.03	581.46	747.56
Total cost/ft	222.21	177.23	227.85

BENEFITS

The benefits accuring from the use of fly ash/cement packing would be:

- improved strength of the pack
- improved strata control
- more rapid packing
- reduction in packing costs
- reduction of foreign exchange costs

- reduced load on transportation system
- utilisation of a waste material
- reduction in face end manpower
- reduction of wood use underground

Further cost reductions can be achieved by eliminating the cement, replacing it with anhydrite. This aspect should be studied further.

CONCLUSIONS AND RECOMMENDATIONS

The authors conclude that fly ash/cement packing is economically attractive on the basis of these costs, and technically attractive because of the better pack strengths and better strata control possible by its use.

It is recommended that the trial proposal outlined here be followed, carefully monitored by CBDC and if satisfactory, full fly ash/cement packing implemented at Lingan Mine.

ACKNOWLEDGEMENTS

The assistance of Mr. S. Acker, Mr. W. Langley and Mr. W. Eades during the preparation of this report is gratefully acknowledged.

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3. Cain, P. "An appraisal of fly ash based monolithic packing for use at Lingan Colliery, Nova Scotia"; CANMET Division Report ERP/CRL 86-18(IR).
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APPENDIX A

FLY ASH/CEMENT PACKING AT PARSONAGE COLLIERY

The fly ash/cement packing system consists of two separate slurry circuits, described below. The system is shown diagrammatically in Figure A.1.

FLY ASH SLURRY SYSTEM

The fly ash, wetted to reduce airborne dust, is delivered to the colliery yard in 20 tonne trucks. It is tipped into and stored in a 35 tonne surface bunker. The bunker feeds an AFC which in turn feeds a belt conveyor. The belt conveyor loads the fly ash directly into a 730 L (160 gal) Colcrete SD24 colloidal mixer.

A batch of fly ash slurry is prepared as follows. The mixer is filled to a predetermined level and bentonite and ferrous sulphate are then added in the required amounts. The mixer is then topped up to the 730 L level by adding fly ash. The mixed slurry is pumped into converted mine cars and conveyed underground to a pit bottom pumping station. From there it is pumped to an inbye holding tank (situated 200 - 300 m from the face) along a (76 mm) 3" Victaulic pipe by a CLM 411 monopump. A similar booster pump is located approximately 1250 m from pit bottom in case it is required (Figure A.1). The inbye tank is fitted with compressed air-driven paddles to maintain the fly ash in suspension.

CEMENT SLURRY SYSTEM

Adjacent to the fly ash holding tank is the cement slurry station. This consists of:

a) two GM30 Mindev paddle mixers (256 L, 56 gal)
b) a Colcrete colloidal mixer
c) a single acting Mindev 95 mm pump
d) a 30 kW (40 hp) electrohydraulic power pack

To prepare the cement slurry, twenty gallons of water is fed into the colloidal mixer and six 25 kg bags of OPC are added. From the mixer the slurry is fed to the GM30 mixing tanks.

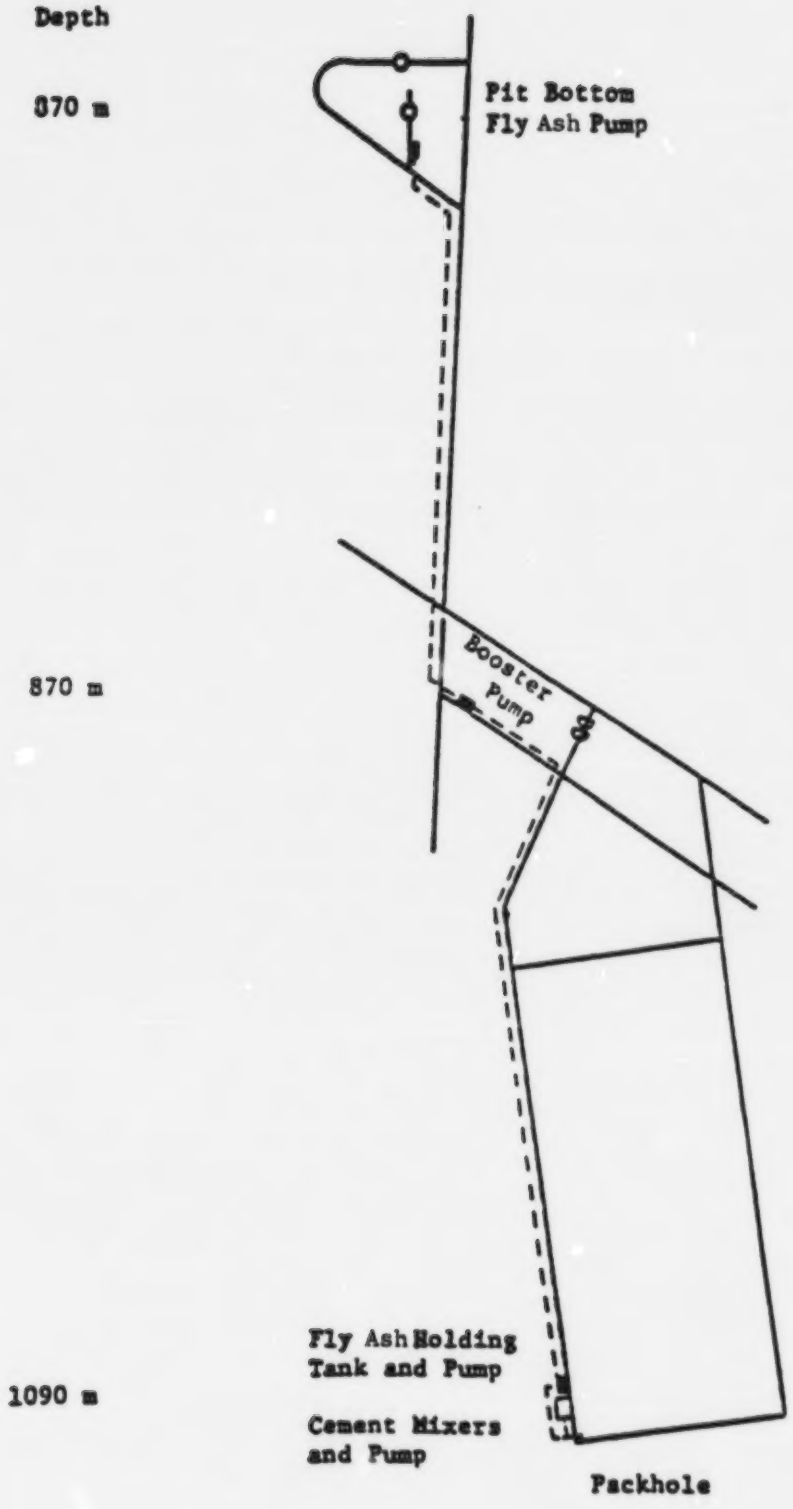


Figure A.1 - Schematic layout of fly ash/cement packing

PACKING PROCEDURE

The packhole is defined by a sheet steel curtain and very little preparation is required. The cement is pumped from the GM30 tanks at a rate of 55 L/min (12 gpm) where it mixes with the fly ash, pumped at 182 L/min (40 gpm) at CLM 411 monopump in a special gun. Both grouts are delivered along 32 mm (1 1/4") armoured flexible hose.

The mixture gels instantly. A packing rate of up to 22 m^3/hour can be achieved, but the limited size of the fly ash holding tank requires an intermittent packing process to allow refilling.

FLASHPACK PREPARATION AND PLACEMENT COSTS AT PARSONAGE COLLIERY

The packing system absorbs eight man shifts per day. Detailed costs are shown below:

SURFACE

1 man per coaling shift = 2 man shifts per day

Average EMS*	$ 53.52
Average wages charged per shift	$ 30.40
Average cost per shift	$ 83.92
Average cost per day	$167.84

*Earnings per man shift

PIT BOTTOM PUMPING STATION

1 man per coaling shift = 2 man shifts per day

Average EMS	$ 63.14
Average wages charged per shift	$ 30.40
Average cost per shift	$ 93.54
Average cost per day	$187.08

Y1 INTAKE PUMPING STATION

1 man per coaling shift = 2 man shifts per day

Average EMS	$ 78.24
Average wages charged per shift	$ 30.40
Average cost per shift	$108.64
Average cost per day	$217.28

PACKHOLE

1 man per coaling shift = 2 man shifts per day

Costs are the same as the Y1 pumping station, i.e. $217.28/day.

TOTAL COSTS

Surface	$167.84 per day
Pit Bottom Station	$187.08 per day
Y1 Station	$217.28 per day
Packhole	$217.28 per day
Total Cost	$789.48 per day

Using an average daily saleable output of 1328 tonnes per day, the average manpower costs are $0.59/tonne.

FLASHPACK EQUIPMENT COSTS AT PARSONAGE COLLIERY

Much of the equipment required was fabricated at the pit from scrap or salvaged materials. Costs for each location are detailed below.

SURFACE

35 tonnes capacity fly ash bunker (pit labour costs only) (made at the pit from disused boiler house bunkers).	= $ 1000 (est.)
500 mm armoured conveyor with 48 kW (65 hp) drive.	= $36000 (est.)
Huwood T.B. 40 - 36" belt conveyor.	= $30000 (est.)
Colcrete S.D.24 colloidal mixer (730 L, 160 gal) capacity.	= $ 6840
Six 2275 L (500 gal) capacity transporter tanks (fabricated at the pit) at $500 each.	= $ 3000 (est.)

PIT BOTTOM PUMPING STATION

CLM 411 monopump (30 kW, 40 hp drive).	= $ 9224
Two thousand 76 mm (3") diameter Victaulic pipes at $30 per 6 m length plus $13 per housing.	= $14000 (appx)

Y1 INTAKE PUMPING STATION

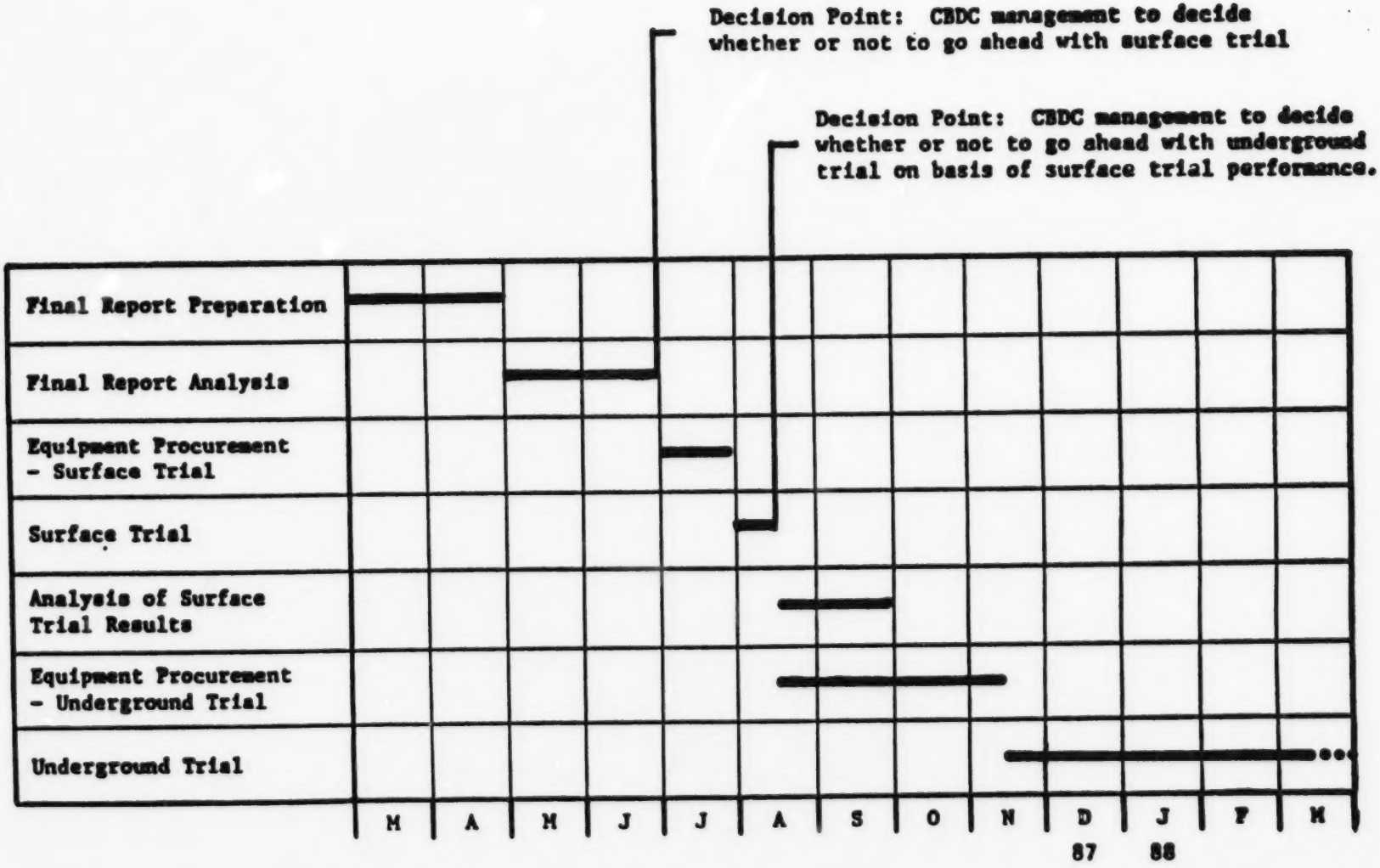
1820 L (400 gal) capacity fly ash mixing tank with paddle mixer and Eimco compressed air motor (assembled at pit).	= $ 500 (est.)
CLM 411 monopump.	= $ 9224
Mindev 30 kW (40 hp) power pack.	= $13096
Two Mindev G.M. 30 agitation tanks at $2660.	= $ 5320
Colcrete S.D.4 colloidal cement mixer.	= $ 6842
Mindev ramp pump (95 mm).	= $ 9046
Two 32 mm (1.25") diameter flexible armoured hose, 200 m long at $900 per 90 m length.	= $ 4000

PACKHOLE

Sheet steel curtains.	= $ 100 (est.)
Two mixer guns (made at pit).	= $ 100 (est.)
Trailing and control cables will be required at an approximate cost of $4000.	= $ 4000
The total cost of equipment for the installation.	$132000 (appx)

The labour costs of installation have not been identified. Using a face advance of 2000 m, a daily advance of 2.54 m and an average daily output of 1328 tonnes per day, the equipment costs per tonne can be calculated as $0.12. This will decrease if the face advances past the 2000 m mark.

APPENDIX B


Decision Point: CBDC management to decide whether or not to go ahead with surface trial
Decision Point: CBDC management to decide whether or not to go ahead with underground trial on basis of surface trial performance.
Final Report Preparation
Final Report Analysis
Equipment Procurement - Surface Trial
Surface Trial
Analysis of Surface Trial Results
Equipment Procurement - Underground Trial
Underground Trial
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APPENDIX C

PROPOSED EQUIPMENT COSTS

Item	Quantity	Size	Life	Unit Cost ($ K)	Extended Cost
Storage Silos	2		10	60	120
Powder Blender	1		10	20	20
Material Cars	18	4.5 tonnes	5	9	162
Tank Cars	10	750 litres	5	3	30
Storage Bunker (Underground)	1	6 tonnes	3	88	88
Power Packs	2		3	20	40
Pumps	2		3	15	30
Mixers	2		3	8	16
				TOTAL	506

Assuming:

1) equipment has no value at the end of its life.
2) wall advance of 2438 m (8,000 ft) and a life of 3 years.

$$\text{Equipment costs/m} = \frac{\text{Extended Cost (\$)}}{\text{Life (yrs) advance/year (m)}}$$

$$= \$135.83/\text{m or } \$41.40/\text{ft}$$

Installation costs for the surface and underground equipment are $8,000 and $3,000 with lifetimes of 10 years and 3 years respectively. Thus the total equipment and installation costs/m are $135.83 plus $2.23/m installation costs, or $138.06/m ($42.08/ft) total. Equivalent costs for Astrapack are $22.11/m or $6.74/ft.

MATERIAL COSTS

CURRENT PACKING METHOD

Astrapack	$311.75 tonne
Shipping Cost	$100.00 tonne
Storage	$ 26.00 tonne
	$437.75 tonne

usage/m^3 - 0.35 tonnes

cost/m^3 - $153.21

cost of packing bag - ≈25.71/m^3

Total Astrapack cost/m^3 - $178.92

Astrapack volume/m^3 advance - 2.69 m^3

Cost of Astrapack/m^3 advance - $481.29 or $146.70/ft

WOODEN CHOCKS

The proposed trial would retain the breaker chock at the waste edge, but would replace one or both of the chocks next to the gateroad.

Number of blocks used in highside chock:

21 x 1.52 m (5 ft) blocks @ $6.60	$138.60
36 x 0.76 m (2.5 ft) blocks @ $3.30	$118.80
	$257.40

Each chock runs 1.52 m, therefore the cost/m is $169.34 or $51.61/ft.

Number of blocks used in lowside chock:

26 x 0.76 m (2.5 ft) blocks @ 3.30 - $85.80

These chocks are spaced intermittently. Assuming one chock/15.2 m (5 ft) advance, the lowside chock costs $56.29/m or $17.16/ft.

FLASHPACK MATERIAL COSTS

Material	Material Use/m^3	Cost/tonne fob mine ($)	Cost/m^3 ($)
Fly Ash	1.148 tonnes	17	19.5
Aluminum Sulphate	0.086 tonnes	335.67	28.87
Cement	0.265 tonnes	126	33.39
		TOTAL	$81.78/$m^3$

Two pack designs are recommended in the proposal; simple Astrapack replacement and total backfilling. For Astrapack replacement, Flashpack use is 2.69/m^3/m advance, costing $220.00/m or $67.06/ft. For total backfilling, Flashpack use is 7.48 m^3/m, costing $611.73/m or $186.46/ft.

COSTS

A total capital investment of $517,000 will be necessary before Flashpack can be utilized. The list of necessary equipment given in the previous section demonstrates where this cost is derived from. Assuming that Flashpack is used on an east side wall with an approximate total advance of 8,000 ft, then there is a cost of $64.63/ft of advance (this assumes that the equipment has no value left at the end of the wall's advance which will not be the case).

If the present monolithic pack is replaced, there will be approximately .82 m^3/ft advance of Flashpack. At a cost of $81.77/$m^3$ then the cost for materials is $67.05/ft advance. This gives a total cost of 131.68/ft advance.

If the two wooden roadside packs are replaced with Flashpack, then approximately 2.28 m^3/ft advance of Flashpack will be required. This gives a cost of $186.44/ft advance. With equipment cost added in, total cost will be $251.07/ft advance.

Current packing costs are estimated at $146.71/ft advance for the monolithic packing material plus $7.00/ft advance for the packing equipment.

The costs of the wooden chocks are estimated at $51.48/ft advance for the highside, roadside wooden chock and $17.16/ft advance for the lowside, roadside wooden chock. This gives a total packing cost of $222.35/ft advance.

Table C.2 below gives a summary of the material and equipment costs. The cost of highside breaker chock is not included.

Table C.2 - Summary of material and equipment costs

Type of Packing (Equipment Costs Included)	Cost ($/ft advance)			
	Wood Chocks	Astrapack	Flashpack	Total
Present Monolithic Pack	68.64	153.71	-	222.35
Partial Replacement Flashpack	68.64	-	131.68	200.32
Total Replacement Flashpack	-	-	251.07	251.07

These figures are based on the assumption that the cost of required equipment is written off over the life of one longwall. The surface silos have an expected life of 10 years and the back material can have an expected life of five years which, when taken into consideration, will reduce the packing cost per foot.

Labour costs should remain the same for the two operations. At present, a total of five men are required for pack installation. With Flashpack, two men will be required for the mixing station in the top level, one man will be required on surface to fill the material cars (not a full-time position) on at least two shifts and two men are required at the packhole. (Only one man will be required at the packhole if the Flashpack is used to replace the current monolithic pack.) Two men will be required if the wooden chocks are replaced so they can spell each other on the nozzle.

APPENDIX D

AVAILABLE SAFETY AND HEALTH DATA FOR FLASHPACK CONSTITUENTS

ALUMINUM AND FERROUS SULPHATE

The safety and health data for aluminum and ferrous sulphate from information supplied by the NCB Western Area Scientific Department are given below:

Threshold Limit Values 1980:

	Airborne Particles mg/m^3	
	T.L.V. T.W.A.	STEL
Aluminum Sulphate Salts	2	-
Iron, Soluble Salts (as Fe)	1	2

Aluminum Sulphate

Aluminum sulphate hydrolyses readily to form some sulphuric acid which acts as a tissue irritant, particularly to the lungs. It is used as a general food additive for neutralisation and buffering purposes (control of pH). In solution aluminum sulphate has a pH = 3 to 3.5.

Ferrous Sulphate

Ferrous sulphate does not hydrolyse in a similar manner, but in air, it oxidises to ferric sulphate, which hydrolyses in the same way as aluminum sulphate, a ferric sulphate solution having a pH = 2.5 to 3 (compare with ferruginous mine water). Ferrous sulphate is used as a nutrient and/or dietary supplement food additive as well as a trace mineral added to animal food; it is a substance migrating to foods from packaging materials.

In general terms, although ferrous sulphate is a mild reducing agent and in oxidised form, as ferric sulphate, it is potentially more acidic than aluminum sulphate; in practice it is not likely to present a significantly greater hazard. Contamination of the skin, eyes and mucous membrane. Inhalation and ingestion of both aluminum and ferrous sulphate powders is likely to have an irritant, although not generally permanent, effect and should therefore be avoided.

In context the use of either compound in conjunction with the cement used for packing, the recommended protective clothing, goggles, dust masks, gloves, etc. should provide adequate protection.

CEMENT

Handling procedures can be summarised by the following generalised terms:

PRECAUTIONS

- avoid creating dust
- avoid inhalation of dust
- avoid skin and eye contact
- wear full protective clothing, including goggles, dust mask, suitable gloves and waterproof leggings particularly during prolonged or frequent use
- provide eye washing facilities

FIRST AID

Eye - Flush copiously for at least 15 minutes. If irritation persists seek medical advice.

Skin - Flush copiously with water. If irritation persists seek medical advice.

Inhalation - Remove to fresh air. If discomfort persists seek medical advice.

Ingestion - Give plenty to drink. If massive amount ingested or if discomfort persists, seek medical advice.